# CONTOUR GENERATION FOR MASK PROJECTION STEREOLITHOGRAPHY 3D PRINTING

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## SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis, and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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# ABSTRAK

Kemajuan terkini dalam teknologi pencetakan 3D telah membawa kepada penghasilan mesin pencetakan 3D berasaskan pancaran-bertopeng. Proses ini menggunakan tenaga cahaya UV bagi membentuk objek nyata dari resin penyembuhan-foto. Pancaran kontur dijanakan dengan mengiris model CAD STL kepada lapisan-lapisan kontur 2D yang kemudiannya disalurkan kepada alat pemancar lapisan demi lapisan berasaskan ketinggian binaan. Pengkomputan bagi penjanaan lapisan-lapisan kontur 2D adalah sangat intensif. Algoritma penjanaan kontur yang sedia ada memerlukan masa pengkomputan yang lama. Ini kerana algoritma tersebut perlu mengiris dan mengkomput setiap satu lapisan sesebuah model STL sebelum proses pencetakan bermula. Dalam usaha bagi mengurangkan masa pengkomputan, algoritma yang baru dan lebih pantas diperlukan. Lantaran itu, algoritma penjanaan kontur lantas dibentangkan di dalam kajian ini. Kaedah ini menghasilkan satu lapisan kontur secara lantas apabila parameter ketinggian binaan disuapkan ke dalam algoritma tersebut. Algoritma tersebut mengandungi beberapa algoritma seperti algoritma pengirisan, algoritma pemetaan garisan pixel, dan algoritma gelungan kontur. Algoritma pengirisan menggunakan model persilangan garisan-satah untuk menghasilkan segmen garisan rawak apabila ia menerima satu faset STL. Segmen-segmen garisan ini kemudiannya dipetakan berdasarkan resolusi alat pemancar dengan menggunakan algoritma pemetaan garisan pixel. Kemudian, garisan-garisan pixel tersebut dihubungkan untuk membentuk satu atau lebih gelungan kontur melalui algorithm gelungan kontur. Hasil dari setiap algoritma-algoritma tersebut dikaji secara mendalam. Pengukuran masa pengkomputan diambil menggunakan objek <QElapsedTimer> di dalam Qt Creator dan diukur dalam millisaat. Keputusan hasil kajian menyatakan algoritma-algoritma tersebut menjanakan lapisan-lapisan kontur dengan tepat. Malah dengan menggunakan model STL berpoligon tinggi, algoritma penjanaan kontur masih dapat menjanakan lapisan kontur secara purata 960.15% lebih pantas dari algorithm Park dan 169.15% lebih pantas dari perisian komersial Slic3r.

## ABSTRACT

Recent advancement in 3D printing technology has led to the development of projection mask stereolithography 3D printing process. This process harnesses the power of UV light contour projection to cure photocurable resin. The contour projection is generated by slicing STL CAD model into layers of 2D contours which is then fed into the UV projection device layer-by-layer with respect to the build height. Generation of the layers are computationally intensive. Existing contour generation algorithm requires long computational time to generate the contour layers especially for high polygon models. This is because the existing approach has to slice and compute every single layer of the STL model before the printing process starts. In an effort to reduce the computational time, a new and faster algorithm is required. Thus, a real-time contour generation algorithm is presented in this research. The real-time contour generation approach instantly generates single layer of contour whenever the build height parameter is fed into the algorithm. The algorithm composes of multiple algorithms such as slicing algorithm, pixel line mapping algorithm, and the contour loop algorithm. The proposed slicing algorithm uses line-plane intersection model to generate arbitrary line segment when it receives an STL facet. These line segments are mapped based on the projection device display resolution by the pixel-line mapping algorithm. Then, the pixelated line segments are connected to form single/multiple contour loops using contour loop algorithm. The results of each algorithms are thoroughly evaluated. Computation time measurement is taken using <QElapsedTimer> object in Qt Creator and measured in milliseconds. It is later found that the algorithms able to correctly generates the contour projection layers. Even with the high polygon STL model, the contour generation algorithm able to perform on average 960.15% faster than Park algorithm and 169.18% faster than commercial software Slic3r.

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## LIST OF SYMBOLS

| | |
|---|---|
| $C_d$ | Cure Depth |
| $D_p$ | Depth of Penetration |
| $E_{max}$ | Maximum Energy of Laser |
| $E_c$ | Critical Energy Dosage |
| $\alpha$ | Photochemical Parameter |
| $\beta$ | Photonics Parameter |
| $c$ | Speed of Light |
| $h$ | Planck's Constant |
| $N_{av}$ | Avogadro Constant |
| $P_L$ | Laser Power |
| $W_o$ | Beam Width |
| $k_t$ | Termination Constant |
| $k_p$ | Propagation Constant |
| $p_c$ | Extent of Polymerization |
| $\epsilon$ | Molar Extinction Coefficient |
| $\lambda$ | Wavelength |
| $\phi$ | Quantum Yield |
| $PI$ | Photoinitiator Concentration |
| $z_c$ | Cure Depth |
| $x$ | X component |
| $y$ | Y component |
| $z$ | Z component |
| $P_o$ | Starting point of the line segment |
| $P_f$ | Ending point of the line segment |
| $s$ | Interpolation parameter |
| $AR$ | Aspect Ratio |
| $AR'$ | Modified Aspect Ratio |
| $R, V, W$ | Piecewise Variable |
| $NC$ | Normalized Correlation |
| $O$ | Big-O Notation |

## LIST OF ABBREVIATIONS

| | |
|---|---|
| 2D | Two-Dimensional |
| 2PP | Two-Photon Polymerization |
| 3D | Three-Dimensional |
| 3DP | Binder Jetting |
| AM | Additive Manufacturing |
| ASCII | American Standard Code for Information Interchange |
| CAD | Computer Aided Design |
| CAM | Computer Aided Manufacturing |
| CLIP | Continuous Liquid Interface Printing |
| CMM | Coordinate Measurement Machine |
| CNC | Computer Numerical Control |
| CPU | Central Processing Unit |
| CSV | Comma-separated Value |
| CT | Contour Time |
| DIW | Robocasting |
| DLP | Digital Light Processing |
| DMD | Digital Micro-mirror Device |
| EBM | Electron Beam Melting |
| ECC | Efficient Contour Construction |
| FDM | Fused Deposition Modeling |
| GB | Giga-Byte |
| IF | Intersecting Facet |
| LC | Loop Count |
| LM | Layered Manufacturing |
| LOM | Laminated Object Manufacturing |
| PC | Personal Computer |
| RAM | Random Access Memory |
| RP | Rapid Prototyping |
| SD | Standard Deviation |
| SLA | Stereolithography 3D Printing |
| SLM | Selective Laser Melting |

| | |
|---|---|
| SLS | Selective Laser Sintering |
| STL | STereoLithography CAD format |
| UV | Ultraviolet |

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